

## **Blue Whale Behavioral Response Study & Field Testing of the New Bioacoustic Probe**

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### **LONG-TERM GOALS**

#### *Task 1: Blue Whales Behavioral Response Study*

Specific studies on the impact of ship noise and have not been widely conducted and little progress has been made toward an understanding of its impact (Southall 2005). Similar data gaps exist for the impact of Navy sonars on baleen whales. The PCAD model (NRC 2005) for assessing sound impacts on marine mammals calls for studies on sound source characteristics and the behavioral impact of specific sources on individual animals. Our goal is to understand the vocal and behavioral response of individual blue whales to high-intensity ship noise, resulting from the close geographic association between known foraging grounds and commercial shipping lanes off California. To accomplish this goal we deploy acoustic recording tags on individual blue whales within and near the shipping lanes e concurrently monitoring shipping traffic using AIS. The behavioral reaction of the whale to ship is then evaluated based on the tag data, the overall noise level, how close the ship approached. We also will conduct opportunistic studies of blue whale response to Navy sonars in the southern California region.

#### *Task 2: Field testing the new Bioacoustic Probe:*

Tagging studies of odontocetes have yielded incredible insights into the diving, movement, and daily activities patterns of several species. Missing from most of these studies has been information on the acoustic environment in which the animal is living and the sounds produced by the animals during different activities. Connection of the acoustic environment and the sound production of the animal is

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particularly important when evaluating foraging behavior and response to natural and anthropogenic noise sources. Working with Greeneridge Sciences, we will use the new BProbe (aka Acousonde) to initiate studies of beaked whale and other large odontocete whale species in the Pacific. Although our aim is to address several scientific questions relating to diving behavior, vocal behavior, and swimming mechanics with the data collected during these deployments, the primary goal of this project is to conduct field tests of the Acousonde with cetaceans and to refine the operation of the tag for robust field operation in the future. Because our primary mission is to field test the tag, we will aim to deploy the Acousonde on a wide variety of large odontocetes including beaked whales, pilot whales, false killer whales, bottlenose and Risso's dolphins, and sperm whales.

## **OBJECTIVES**

### *Task 1: Blue whale behavioral response study:*

Our specific objectives are the following:

- (1) Do blue whales exposed to high-intensity ship noise or sonar signals change their calling or diving behavior?
- (2) What is the form of the response (cessation of feeding, change in orientation, change in vocalization rate or intensity, change in swimming speed, etc.)
- (3) Is there a threshold sound level that elicits a response by blue and humpback whales?
- (4) How long does the behavioral reaction persist relative to the increased noise level?
- (5) What are the potential energetic and social costs of any response to noise?

### *Task 2: Field testing the new Bioacoustic Probe*

The target specifications of the Acousonde include maximum depth of 3000m, maximum sustained acoustic sample rate of 230kHz, storage of 8Gb, 2 channels of acoustic data, and 3-dimensional accelerometer and compass. Our primary goal is to evaluate the functionality of the tag when used with odontocetes, as well as tagging techniques, and tag flotation design.

## **APPROACH**

### *Task 1: Blue whale behavioral response study:*

We evaluate the behavioral response of blue whales to intense ship noise using suction-cup attached acoustic recording tags and GPS Fastlock location tags (Figure 1). The proximity of shipping routes into southern and central California ports with predictable blue whale feeding grounds makes this an ideal location of the study of the impact of intense low-frequency noise on whale behavior (Figure 2). We monitor the vocal and dive behavior of blue whales using the B-Probe (Greeneridge Sciences) and the fine-scale movements of whales using the MK10 (Wildlife Computers). The B-Probe also records temperature, depth, and 2-axis acceleration, enabling the derivation of instantaneous body orientation (i.e., tilt and roll), as described by Goldbogen *et al.* (2006). The MK10 records depth enabling the two tag records to be synched when deployed on the same animals or two animals in a pair.

Acoustic data collected by the B-Probe is analyzed to determine the presence and spectral characteristics of sounds produced by the whales, the ambient noise level prior to ship approach, and the received sound level of the passing ship. Flow noise generated when the animals moves through the water masks other sounds and prevents accurate measurement of the noise level produced by passing ships. To address this, we measure ambient noise levels when the animal is relatively stationary and therefore the flow noise is very low, such as when the whale is at the top of a feeding lunge, or when it is traveling slowly. Ambient noise measurements are made when no ships are

present and during ship passage to determine the level of noise the whale was exposed to. When the whale is swimming, the amplitude of the flow noise is calibrated to provide estimates of swim speed. Dive depth and body orientation are measured by the sensors on the tag, and additional behavioral variables are derived from the auxiliary sensors, including acceleration, fluke rate, and feeding behavior, such as the presence of vertical or horizontal lunges. These behavioral measures are used to describe swimming mechanics, which may be used to derive energy expenditure (Goldbogen *et al.* 2006).



***Figure 1. Suction cup tag being deployed on a blue whale in the Santa Barbara Channel on 16 September 2009.***



***Figure 2. Blue whale with Bprobe attached surfacing near approaching ship in the Santa Barbara Channel on 14 August 2008.***

Position data from the MK10 is used to evaluate fine-scale movements of the animals within and near the shipping lanes. Nighttime movements and behavior which cannot be effectively monitored by the

research team are recorded on the MK10 for later evaluation of close ship approaches and behavioral changes during this period.

Ship locations are monitored using a real-time AIS receiver installed aboard the tagging boat and from two shore stations near Santa Barbara. The shore stations provide the entirety of the ship approach into the Channel and on to the Port of Los Angeles or Long Beach. The boat-mounted AIS provides real-time information to the tagging team on the closest point of approach to the tagged whale and the speed and track of the approaching vessel so that the team can move out of the shipping lanes before the ship is very close. Once tagged, the tagged whale's position and surface behavior are monitored and the whale is photographed for individual ID. Skin is collected from the tagged whale to allow for the evaluation of sex-based differences in behavioral reaction to high-intensity noise. The photo-ID of tagged whales is compared to Cascadia's catalog and database of sighting histories, providing information on minimum age, movements, and sex for many of the animals. This information is then combined with tag-observed behavioral and acoustic variables and ship characteristics. All variables are evaluated within the context of the local ambient noise prior to close ship approach and are compared to whale behavior in the absence of high-intensity noise.

Although we do not yet have enough data to carry out robust statistical analyses of changes in whale behavior during ship passage, our aim is to evaluate a number of variables including changes in dive depth, surfacing rate, time spent at depth and surface, tilt, roll, swimming speed, acceleration, fluking rate, presence and number of feeding lunges, the presence of calls, and the spectral character of calls versus the measured sound level characteristics. Blue whale calling behavior on feeding grounds has been previously studied, including diving and swimming behavior during calling (Oleson *et al.* 2007a, Oleson *et al.* 2007b), such that changes in calling can be evaluated within this context. Because sound exposure levels will vary among tagged whales, we plan to compare behavioral variables using relational statistical approaches, such as generalized regression models. These approaches allow us to evaluate behavioral changes along a continuum of sound levels and to account for differences in behavior due to season, location, sex, or the presence of other individuals, factors that may influence the reaction of the tagged animal to noise (Fristrup *et al.* 2003).

This project is co-managed by the lead investigators Erin Oleson of UCSD and NOAA and John Calambokidis of Cascadia Research. Erin and John have been studying the diving and vocal behavior of blue whales using suction-cup attached tags for nearly 10 years. John has extensive knowledge of blue whale distribution and behavior and has maintained a photo-ID catalog of eastern North Pacific blue whales since the late 1970s. Megan McKenna, a PhD student at UCSD, is participating in field work and using parts of the dataset for her Doctoral dissertation. Megan is also providing information on trends in ship traffic from the AIS data and ship noise characteristics, including individual ship sound source characteristics based on continuous acoustic recordings using High-Frequency Acoustic Recording Packages (HARPs) deployed at several sites in and around the Santa Barbara Channel. This work is conducted in collaboration with Channel Islands National Marine Sanctuary and they are providing ship support on the R/V Shearwater.

#### *Task 2: Field testing the new Bioacoustic Probe:*

Tagging efforts will occur off Southern California and in Hawaii in conjunction with ongoing survey and tagging efforts in those regions. Off Southern California, our efforts will be coordinated with visual and acoustic surveys underway at the instrumented Southern California Offshore Range (SCORE). The real-time acoustic monitoring capability significantly increases the probability of finding whales for this study. In addition, the acoustic data collected by the tag could be compared to

that collected on the seafloor hydrophones for data quality purposes and to determine the feasibility of recording odontocete calls on the tag. Tagging with the Acousonde in the southern California region will be conducted with personnel at the Range to direct us to individual or groups of beaked whales or pilot whales for tagging.

**Table 1. Summary of suction cup tag deployments on blue whales in and around Santa Barbara Channel in 2008 and 2009.**

DateTimeOn	OnLat	OnLong	OffTime	H-on	Comments	Shipping lane/ship observations
<b>Bprobe acoustic tag</b>						
14-Aug-08 14:32	34 09.05	119 51.38	14-Aug-08 16:09	1.6		In S lanes, ship passes .7 nmi away
15-Aug-08 15:55	34 06.61	119 38.00	15-Aug-08 17:33	1.6	No acoustics	In S lanes, no ship passes
15-Aug-08 18:22	34 06.46	119 36.05	15-Aug-08 21:26	3.1	Dual deploy Bprobe and Mk10, no acoustics	In S lanes, no ships seen, no acoustics
16-Aug-08 10:44	34 06.7	119 37.8	16-Aug-08 21:20	10.6	No VHF, whale watch boats 1100-1240	In S lanes, ship CPA >500 at 1619, 2nd ship CPA <200m at 1658
9-Sep-08 13:38	33 57.54	118 45.81	9-Sep-08 15:25	1.8	Near Pt Dume	>5 nmi from lanes
12-Sep-08 14:30	34 08.28	120 00.27	12-Sep-08 15:47	1.3		3.3 nmi S of lanes
3-Aug-09 14:00	34 09.00	119 49.74	3-Aug-09 18:12	4.2		S edge of shipping lanes
4-Aug-09 14:03	34 03.07	119 14.18	4-Aug-09 16:54	2.9		In shipping lanes
5-Aug-09 10:45	34 03.56	119 13.66	5-Aug-09 15:12	4.5	Ship comes through at 1123 very close to whales	Ship comes through at 1123 <200m to whales
16-Sep-09 15:06	34 02.95	119 13.74	Problem		Trail of two, had been mid of trio	In shipping lanes, ship passes ~1000m at 18:33
16-Sep-09 16:43	34 03.22	119 13.39	16-Sep-09 23:42	7.0	Lead of two, both w/ chopped df, dual deploy	In shipping lanes, ship passes ~1000m at 18:33
9/21/2009 11:58	34 10.37	120 37.72	9/21/2009 17:53	5.92	One of friendly pair of humpback whales	W of San Miguel near new shipping routes
9/21/2009 16:30	34 06.99	120 36.67	9/21/2009 17:30	1.00	Trail of pair	W of San Miguel near new shipping routes
Total hours				45.4		
<b>Mk10 Fastlock GPS TDR tag</b>						
14-Aug-08 14:32	34 09.05	119 51.38	14-Aug-08 16:15	1.7	Dual deployment with Bprobe	In S lanes, ship passes .7 nmi away
15-Aug-08 18:22	34 06.46	119 36.05	16-Aug-08 18:30	24.1	Dual deploy Bprobe	In S lanes, left prior to dark, no ships seen
8-Sep-08 15:45	33 58.01	118 45.71	9-Sep-08 03:35	11.8	Near Pt Dume	>5 nmi from lanes
10-Sep-08 15:55	34 08.82	119 56.32	11-Sep-08 03:40	11.8	leave with tag on;	1.2 nmi from S-bound
29-Jul-09 12:27	34 06.91	120 06.03	30-Jul-09 01:02	12.6		5.8 nmi S of lanes, Mk10 shows does not get closer
3-Aug-09 14:00	34 09.00	119 49.74	3-Aug-09 19:12	5.2		S edge of shipping lanes
4-Aug-09 14:03	34 03.07	119 14.18	4-Aug-09 19:12	5.2		In shipping lanes
5-Aug-09 07:47	34 02.73	1119 13.04	5-Aug-09 14:01	6.2		Ship comes through at 1123 <200m to whales
16-Sep-09 16:43	34 03.22	119 13.39	16-Sep-09 23:38	6.9	Lead of two, both w/ chopped df, dual deploy	In shipping lanes, ship passes ~1000m at 18:33
16-Sep-09 18:56	34 03.69	119 13.55	17-Sep-09 00:19	5.4	Trail of two	In shipping lanes
Total hours				90.9		

Off the Island of Hawaii, existing tagging efforts focused on collection of dive and movement data of beaked whales, pilot whales, and false killer whales (e.g. Baird *et al.* 2006) would provide a unique

opportunity to refine tag attachment methodology and compare the data collected by the Acousonde to the data sets collected by these other tag technologies. Surveys for odontocetes are conducted in Hawaii approximately 3 months per year, providing ample opportunity to deploy tags on various odontocete species and compare tag attachment methods.

## WORK COMPLETED

### *Task 1: Blue whale behavioral response study:*

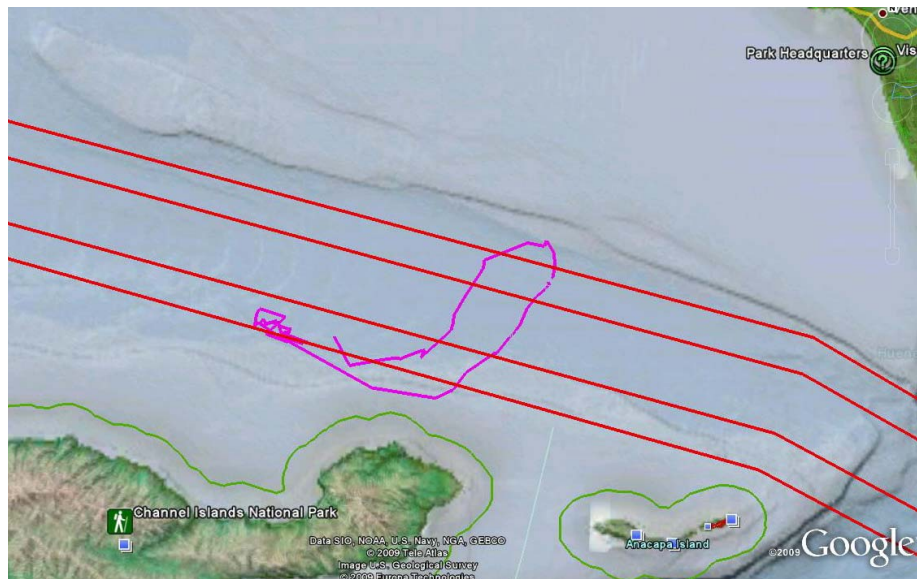
Deployments on blue whales in and around the Santa Barbara Channel shipping lanes were conducted during four periods in 2008 and 2009 (Table 1). A total of 13 deployments of BProbe acoustic tags and 10 deployments of Mk10 Fastloc GPS tags of over an hour each were completed. These efforts targeted primarily animals in the shipping lanes and successfully documented at least three very close approaches (within 200m) of ships by instrumented animals. Additional approaches of ships at slightly greater distance (200 to 1,000 m) were also documented. There may be additional close approaches that occurred at night and while we were not monitoring the whales, but that may have been recorded and will be evaluated based on AIS ship tracks and known whale movements from Mk10 tags.

### *Task 2: Field testing the new Bioacoustic Probe*

One Acousonde has been ordered, but has not yet been delivered due to delays in the development of tag control software. Delivery of a partially functional tag is expected by the end of the calendar year, with full functionality anticipated sometime in winter or spring 2010. We will begin testing the acoustic-sampling only Acousonde on odontocetes in Hawaii as soon as it is delivered.

## RESULTS

### *Task 1: Blue whale behavioral response study*

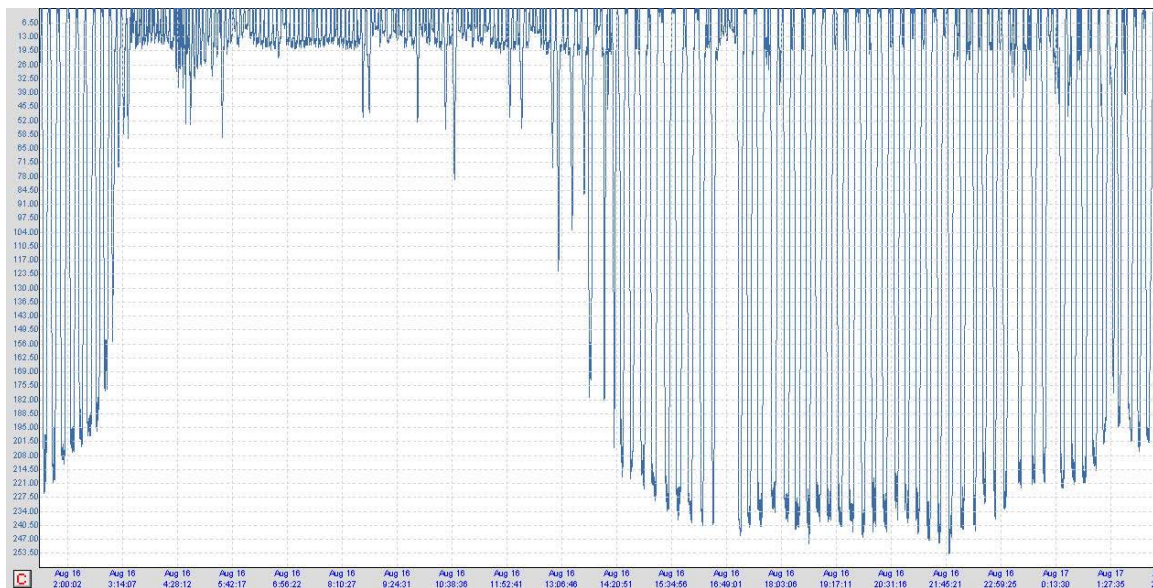


**Figure 3. Track of blue whale over 24 hours period 15-16 August 2008 based on positions from Mk10 Fast-lock GPS tag showing initial tagging in inbound shipping lanes, slow loop taken overnight crossing both inbound and outbound shipping lanes and then return to eventual feeding in inbound lanes over extended period just west of where tagged.**





**Figure 3. Tracks of a pair of whales (both with Mk10 fast lock GPS) tagged in the shipping lane on 16 September 2009 (one at 1643 and the other at 1856). The track ends just before midnight the same day. Whale movements were highly synchronous as they moved in and near the shipping lanes.**



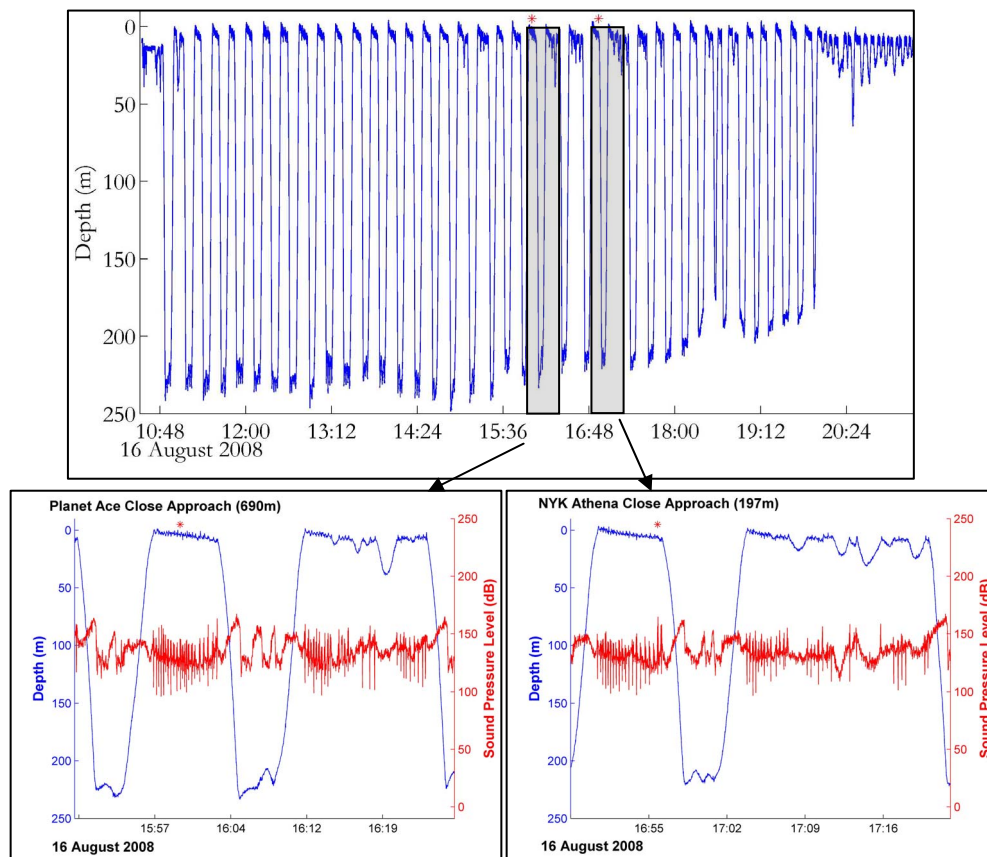
**Figure 4. Dive record over 24 hour period for 15-16 August 2008 from blue whale tagged with Mk10 tag and tracked based on Fast-lock GPS. The period of shallow diving was during night.**

To date we have collected acoustic and high-resolution tracks from three whales that were very closely (<200m) approached by commercial ships within the shipping lanes. Preliminary analysis of these records suggests that the close approach does not elicit a strong reaction by the whales; however, the whales do appear to alter their diving and surfacing behavior slightly for the dives or surfacing period during and immediately following the close ship approach. High-resolution tracks of MK10



tagged animals indicate that whales are foraging within the shipping lanes and remain in the area for at least several hours (Figures 3 & 4). Based on nine BProbe or MK10 records, we have monitored the transition from daytime foraging to nighttime resting behavior, with a clear shift toward shallow dives and more frequent surface series (Figure 4). This behavior within the shipping lanes may leave the animals at greater risk of ship strike than daytime deep foraging behavior.

A pair of tagged whales was subject to close encounters by commercial ships on August 16, 2008. The source level of each ship was measured based on the location information from the AIS and seafloor acoustic recordings on HARPs placed within the shipping lanes. This information was then used to ground-truth the received level recorded on the tag with the estimated received level based on the distance that the ship passed by the diving blue whales. The first ship, Planet Ace, a vehicle carrier traveling 17 kts, had a source level of 181dB re:  $\mu\text{Pa}^2/\text{Hz}$  in the 10-150Hz band. This equates to a received level 124dB re:  $\mu\text{Pa}^2$  at 690m. The measured received sound level on the tag was 127dB re:  $\mu\text{Pa}^2$ . The second close approach was by ship NYK Athena, a container ship traveling 23kts. This ship has a calculated source level of 189 dB re:  $\mu\text{Pa}^2/\text{Hz}$  in the 10-150Hz band based on the seafloor acoustic data and an estimated received sound level of 143 dB re:  $\mu\text{Pa}^2$  at 197m. The received sound pressure level on the tag was 135dB re:  $\mu\text{Pa}^2$  although this was taken several minutes later during a lunge when the ship was then farther away. We anticipate that further evaluation of nighttime tracking and acoustic data may yield additional close approaches that can be evaluated within the context of blue whales shallow nighttime resting behavior.



**Figure 5.** Dive profile of BProbe-tagged blue whale in the southbound shipping lane on 16 August. The gray shading indicates the times of two close approaches by commercial ships. The blow-ups compare the dive record during the close ship approach to the sound level recorded on the tag.

#### *Task 2: Field testing the new Bioacoustic Probe*

The Acousconde acoustic tag has not yet been delivered so no field testing has been carried out. We will begin field tests as soon as the tag is available for use, as early as December 2009.

### **IMPACT/APPLICATIONS**

#### *Task 1: Blue whale behavioral response study*

We anticipate two additional years of field effort toward this project which should yield much more data with which we can evaluate blue whale response to loud ship noise. The results of our tagging and monitoring studies will provide the baseline data needed on sound source (commercial ships and sonars), the behavioral response of blue whales to this source, and an estimate of how these responses may relate to the life functions, such as feeding, migration, and social behavior, of this endangered species. Mounting evidence suggests that high-intensity sounds generated by sonars and airguns can result in stranding or death (Cox *et al.* 2006); yet more subtle may be the chronic effects of increased incidental noise from commercial shipping (Southall 2005). High levels of noise may interfere with blue whales ability to detect sounds such as calls of conspecifics and natural sounds that aid in navigation or foraging. Noise may affect reproductive or immune functions and cause more generalized stress.

### *Task 2: Field testing the new Bioacoustic Probe:*

The Acousonde acoustic recording tag includes improved acoustic and auxiliary sensors, providing the capability to collect acoustic data up to 125 kHz bandwidth and animal orientation in 3-dimensions, in addition to dive depth. The new tag should be capable of providing valuable acoustic and dive data from medium to large odontocete cetaceans, a technological and scientific improvement over the previous tag technology. Acoustic tag studies are needed on odontocetes as these species have displayed vulnerability to anthropogenic noise sources. Our goal is to bring the new tag into a field-ready state for community-wide use of the tag with a variety of cetacean species to study vocal and dive behavior and evaluate noise response.

## **RELATED PROJECTS**

### *Task 1: Blue whale behavioral response study:*

Several agencies and institutions are contributing to the greater goals of this project. Support has been provided by the Channel Islands National Marine Sanctuary and Steve Katz in particular, who provided time on their vessel R/V Shearwater in 2009. The Sanctuary conducts aerial surveys within the shipping lanes. Alerting our research team whenever there are whales present in the lanes. They also place naturalists on the whale watch boats to provide information on whale distribution in the Channel. Additional funding has been provided by NMFS Marine Mammal Conservation Division. They are particularly interested in the reaction of the whales to the close ship approach, an inquiry that fits nicely with this work. Finally, High-Frequency Acoustic Recorders (HARPs) have been deployed in the and around the Santa Barbara Channel by Scripps Institution of Oceanography with support from NOAA Fisheries Acoustics Program. The HARPs have provided valuable data on ship occurrence and the spectral and sound level properties of individual ships.

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## **PUBLICATIONS**

### *Conference Presentations:*

McKenna, M.F., E.M. Oleson, J. Calambokidis, S.M. Wiggins, and J.A. Hildebrand. 2009. Noise impact from large commercial vessels on blue whale communication ranges and sound exposure levels in the Santa Barbara Channel. Presentation at the Biennial Conference on the Biology of Marine Mammals. 12-16 October, 2009. Quebec City, Quebec, Canada.

John Calambokidis and Megan McKenna were invited to present results and participate in a panel about ship strike impacts on whales in southern California organized by the Channel Islands National Marine Sanctuary, held in Ventura on 17 July 2009. John Calambokidis has also presented some of the findings to date at two CINMS Sanctuary Advisory Council meetings during their deliberations of ways to reduce ship strikes.